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(54) **Improvements in and relating to breathing apparatus.**

(57) Breathing apparatus for use in contaminated atmospheres and for ensuring the maintenance of a positive pressure over the face of the wearer at all times, comprises a face mask (1) for covering at least the nose and mouth of the wearer and having an inlet (2) and an outlet (3). The outlet (3) is provided with a biassed outlet valve (4) which opens only when a preset differential pressure is achieved within the face mask. The inlet (2) is connected in parallel to two breathable gas supply systems. One system comprises a pump and filter assembly (6, 9) for supplying filtered ambient air to the face mask. The other comprises a controllable valve assembly (13) for controlling supply of compressed air from a cylinder to the face mask. The controllable valve assembly is controlled by a pressure sensitive control (19, 20) such that, under normal operating conditions, the controllable valve (13) remains closed, air to the face mask being provided solely by the pump and filter assembly. However, if the pressure within the face mask (1) relative to ambient pressure at any time drops below a preset minimum which is above ambient pressure, e.g. because of extreme breathing conditions of the wearer or because of reduction in the supply of air by the pump and filter assembly (6, 9), the controllable valve (13) will open to supply air from the compressed air cylinder to the face mask to ensure that the pressure of air within the face mask is maintained at or above the preset minimum at all times.

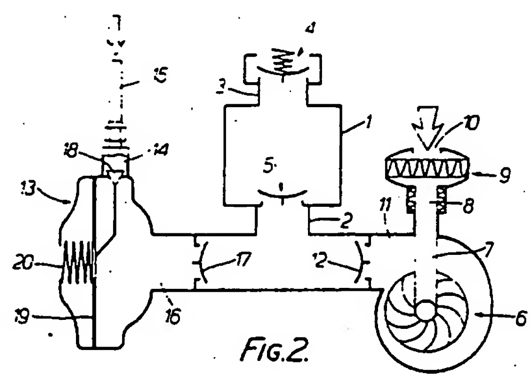



FIG.2.

EP 0 241 188 A1

# Improvements in and relating to Breathing Apparatus

The present invention relates to improved breathing apparatus and is concerned with the types of breathing apparatus known as powered air purifying respirators (PAPRs) and compressed air breathing apparatus (CABA). Both types of breathing apparatus include a face mask for the wearer which is provided with an inlet to which air to be breathed by the wearer is supplied. The air of PAPRs is ambient air which is pumped to the face mask by a battery powered pump carried by the wearer, the air being filtered downstream, or more generally upstream, of the pump. The air for CABA is compressed air, provided either from a compressed air line or a local source of compressed air, e.g. a cylinder which may be carried by the wearer, and which is supplied to the face mask via a pressure controlled or demand valve assembly. Positive pressure versions of both types of breathing apparatus are available, in which the pressure of air within the face mask is maintained at a pressure above ambient pressure by providing in the outlet of the face mask an outlet or exhale valve which will only open when the pressure in the face mask is at a preset level above the ambient pressure. Such positive pressure versions of the above types of breathing apparatus are used, for example, where a worker is operating in a hazardous environment.

Where, for example, a worker is working within a hazardous dust environment, e.g. with asbestos, the use of a positive pressure breathing apparatus may be required at all times. Such a worker may wear a positive pressure CABA supplied with compressed air from a cylinder and in accordance with British Standard No. 4667 part 2; 1974 "Open-circuit breathing apparatus", but the short duration (approximately one hour) and weight (10 kg) of the cylinder renders this of limited use. More usually, the worker will be provided with a positive pressure CABA supplied from a compressed air line and in accordance with British Standard No. 4667 part 3; 1974 "Fresh-air hose and compressed air line breathing apparatus". A major disadvantage of air line supplied breathing apparatus is apparent when two or more workers are working in close proximity and the air lines become entangled. The air lines are also themselves vulnerable to damage. Additionally, a supply of compressed air to the work site is also necessary.

An alternative breathing apparatus is a positive pressure PAPR in accordance with BS 4558; 1970 "Positive pressure, powered dust respirators". While such a breathing apparatus confers mobility on the worker and has a high standard of filtration, towards the end of the working period, the apparatus may suffer from a reduced air flow due to the clogging of the filter with dust or due to a reduced battery voltage. This is characterised by a reduction in the pressure of air supplied to the face mask and possibly the intermittent appearance of pressures within the face mask below ambient pressure. Such an apparatus thus fails to meet the requirement of positive pressure within the face mask at all times and may therefore require the incorporation of a device to warn of the onset of "failure". Such a warning device is difficult to calibrate and may be unreliable in use.

Additionally, with both types of positive pressure breathing apparatus, the pressure within the face mask may intermittently fall below ambient pressure if the breathing rate of the wearer becomes abnormally high, for example, as a result of a high degree of exertion by the wearer. The breathing rate is often denoted by the Minute Volume (Vm), i.e. the amount of air breathed per minute, which is the product of the number of respirations per minute and the tidal volume (Vt). The maximum instantaneous rate (assuming sinusoidal breathing) is approximately three times the Minute Volume. It can be seen that for a man working moderately hard for whom Vm equals 50 litres, the apparatus must supply more than 150 l/min. A Minute Volume of 60 litres requires a supply of 180 l/min. etc. It is said that a trained athlete can achieve a Minute Volume of 100 litres for short bursts, but Minute Volumes of 40 and 50 litres are more common. A positive pressure CABA is normally arranged to supply up to 350 l/min and a positive pressure PAPR is normally arranged to supply up to 200 l/min. but with both subambient pressure within the face mask can occur due to the inertial effects of the demand valve in the case of the CABA and pump restrictions in the case of the PAPR.

The possibility of transient sub-ambient pressures occurring in the face mask is thus very real for both CABA and PAPR and in practice is found to occur.

According to one aspect of the present invention, there is provided a breathing apparatus which is in effect and normally operates as a positive pressure PAPR but which is combined with a positive pressure CABA with the face mask exhale valve and the demand valve of the CABA adjusted relative to each other and to the operation of the pump of the PAPR so that the demand valve of the CABA will open only when the pressure in the face

mask drops below a preset minimum level, which is not achieved during normal operation of the apparatus, to ensure that a positive pressure is at all times maintained in the face mask.

According to another aspect of the present invention, there is provided breathing apparatus comprising a face mask for covering the nose and mouth of the wearer and having inlet means and outlet means for gas, the outlet means being provided with non-return outlet valve means adapted for maintaining a positive differential pressure within the face mask, the face mask inlet means being connected to the outlet of pump and filter means for supplying filtered ambient air to the face mask, said face mask inlet means also being connected to the outlet of controllable valve means having an inlet for connection to the supply of pressurised breathable gas, and a pressure sensitive control means for controlling the controllable valve means and adapted to cause opening of the controllable valve means in the event that the pressure in the face mask falls below a preset minimum relative to ambient pressure which is such that under normal operating conditions the controllable valve means remains closed, filtered ambient air being supplied to the face mask by the pump and filter means.

The control means may be arranged to cause closing of the controllable valve means when the pressure within the face mask rises above a preset level above said preset minimum level.

Embodiments according to the present invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

Figure 1 shows diagrammatically at (a), (b) and (c) breathing patterns under different circumstances;

Figure 2 shows diagrammatically an embodiment according to the present invention;

Figure 3 is a section through an embodiment of apparatus according to the present invention;

Figures 4 and 5 show the embodiment of Figure 3 in use; and

Figures 6 to 9 show modifications of the embodiment of Figure 3 according to the present invention, in use.

Figure 1 (a) shows the pressure within the face mask of a conventional negative inspiration or unpowered respirator or CABA without positive pressure, under conditions of normal use. The pressure, shown on the y axis, varies between positive and negative relative to ambient pressure, which is represented by O, depending on whether the wearer is exhaling or inhaling. Figure 1 (b) shows the pressure within the face mask of a positive pressure PAPR or positive pressure CABA under normal conditions and in which the pressure is in effect lifted wholly above ambient pressure (O), and the pressure within the face mask does not, in normal use, fall below ambient pressure. Figure 1 (c) shows what can happen, for example if the wearer increases exertion or, in the case of a PAPR, the filter becomes clogged or the battery begins to fail. Insufficient air is supplied to the face mask so that, at the peak of inhalation, the pressure within the face mask dips below ambient pressure (O).

Figure 2 shows diagrammatically an embodiment according to the present invention comprising a face mask 1 for covering at least the mouth and nose of the wearer and which is provided with inlet means 2 and and outlet 3. The outlet 3 is provided with a non-return outlet valve 4 which is biassed, for example by a spring, to open only when the pressure within the face mask exceeds ambient pressure by a preset amount. Inlet means 2 may, as shown, be provided with a non-return valve 5, as is conventional, to prevent reverse flow of air through the inlet, but this valve may be dispensed with.

The face mask inlet means 2 is connected to two breathable gas supply systems in parallel. As shown on the right hand side of Figure 2, the system comprises pump and filter means which draws in ambient air and pumps it to the inlet means of the face mask. The pump may, as shown, comprise a fan 6, which may be an axial fan or, as illustrated, a centrifugal fan, which is driven by a battery operated motor (not shown). The inlet 7 of the pump unit is connected to the outlet 8 of the filter unit 9 whose inlet 10 is open to ambient air so that the fan 6 draws ambient air in through the filter and expels it into the outlet 11 of the fan which is connected by a non-return valve 12 to the face mask inlet means.

On the left hand side of Figure 2, the system comprises a controllable valve assembly 13 having an inlet 14 which is connected to a supply of compressed air (not shown), for example as is used for CABA, by a flexible hose 15, and an outlet 16 which is connected by an optional non-return valve 17 to the face mask inlet means 2. The valve assembly 13 comprises a tiltable controllable valve member 18 arranged to control communication between inlet 14 and outlet 16 and which is controlled by a pressure sensitive device within assembly 13 and which senses the difference in pressure between ambient pressure and the pressure in the assembly outlet, which is effectively the same as the pressure in the face mask. The pressure sensing device may, as shown, comprise a diaphragm 19 arranged with one face exposed to ambient pressure and the other face exposed to the pressure within the assembly outlet and which is biassed by a spring 20. Movements of the diaphragm 19 are transmitted by a transmission mechanism to

the valve member 18 to cause tilting of the valve member. The differential pressure at which the valve member 18 will open is set by appropriate adjustment or selection of the bias on the diaphragm which is also arranged so that, after opening, the valve member 18 will be closed when the pressure in the outlet of assembly 13 has risen by a preset amount above the pressure at which the valve member opened.

The differential pressure within the assembly outlet is arranged to be less than that at which the outlet valve (4) in the face mask outlet closes and in effect represents a minimum differential pressure which is to be maintained at all times within the face mask.

The fan 6 is arranged to operate at a rate sufficient to maintain the required positive pressure in the face mask for normal operating conditions, and the bias on the exhale valve and the bias on the diaphragm 19 are adjusted relative thereto to ensure that, under normal operating conditions, the valve member 18 remains closed so that the air required by the wearer ofthe face mask is provided solely by the fan 6, i.e. the apparatus operates as a positive pressure PAPR. If however, the pressure of the air supplied by the fan 6 reduces, due to clogging of the filter or reducing battery voltage, or if the wearer's breathing rate increases to an abnormal level, then at least during inhalation by the wearer, the pressure within the face mask will fall. If it falls to the pressure relative to ambient pressure at which the valve member 18 opens, then compressed air will be supplied through assembly 13 to the face mask to increase the pressure within the face mask to thereby ensure that it does not fall further and specifically does not fall below ambient pressure. Supply of compressed air through assembly 13 will continue until the pressure in the face mask rises by the preset amount determined by the bias of spring 20. At this point, valve member 18 will close and the supply of air to the face mask by pump 16 will be resumed.

During the period that valve 18 is open, non-return valve 12 will close to prevent reverse flow of air through the pump 6 and filter 9 and loss of pressure thereby.

In practice, and under circumstances of abnormal breathing rate, any opening of valve 18 lasts only for a fraction of a second, and only occurs at the peak in inhalation by the wearer. However, if there are insufficiencies arising from clogging of the filter or a reduction in voltage of the battery, the period of each opening of valve 18 will progressively increase as clogging increases or battery voltage reduces and eventually the face mask may be supplied with breathable gas solely through assembly 13. Under these circumstances, the apparatus will operate like a CABA.

Figure 3 shows an embodiment of apparatus according to the present invention and specifically shows in greater detail the fan 6 and filter 9 shown diagrammatically in Figure 2, together with connection of the outlet of the fan 6 and of the valve assembly 13 to a mask. The same reference numerals are used in Figure 3 as are used in Figure 2 for corresponding parts.

The apparatus shown in Figure 3 comprises a connector 21 having an outlet 22 optionally fitted with a conventional threaded coupling ring 23, for connection to the inlet boss of a conventional face mask (not shown in Figure 3). The connector 21 is generally T-shaped and comprises a pair of coaxial inlets 24, 25 communicating with the outlet 22, each of which is provided with an insert 26 which is, optionally threaded to receive a conventional coupling ring 27, 28 similar to the ring 23 on outlet 22. The non-return valves 12,17 as shown in the form of flexible disc valves, are advantageously mounted on the inserts 26.

Fan 6 is mounted, together with its motor 29, in a housing 30 defining the inlet 7 and the outlet 11 of the fan, and may for example be constructed as described in co-pending European Patent Application No. 0164946. Coupling ring 27 is mounted on the outlet 11 of the fan, and, as described in the above referred to co-pending patent application, the inlet 7 is adapted, e.g. threaded, for engagement with the filter canister 9. Coupling ring 28 is mounted on the part of the housing of assembly 13 defining the outlet 16 of the assembly.

It will be appreciated that non-return valve 17 is in fact superfluous and can be omitted. It may however be convenient to provide non-return valves on both of the inlets 24,25 of the connector assembly 21 so that the fan housing can be connected to either of the inlets of connector 21. In operation and while assembly 13 is closed, valve 17 will also be closed but it will in effect open and close with valve member 18.

Figures 4 and 5 show the apparatus of Figure 3 mounted on the face mask 1, in use. Conveniently the battery or batteries for powering the motor 29 are mounted in a housing connected by a lead 31 to the motor. the housing being provided with an on/off switch and arranged for location in a pocket in the wearer's clothing or attached to the wearer's belt as shown in Figure 5.

The compressed air supply connected to hose 15 is provided by a dedicated supply, e.g. a cylinder 33 which incorporates, as is conventional, a pressure regulator 34 and may for example be supported on a belt around the waist of the wearer, as shown in Figure 5, or across the small of the back of the wearer in a special jerkin.

While as described above the housing including the fan and its motor is mounted directly on the face mask, it may alternatively, as shown in Figures 6 and 7, be connected to one of the inlets of connector 21 by a flexible hose 35, the housing 30 then being mounted on a harness or belt for example at the back of the wearer. The housing 30 may have a plurality of inlets connected to the fan inlet, each of which can be provided with a filter canister 9.

It will also be appreciated that the valve assembly 13 including the pressure sensitive control means may take other forms than that shown in Figure 2 or described in United Kingdom Patent No. 2116852, and that the fan and motor may also take other forms. For example, a positive displacement pump may be used and under such circumstances, if the pump itself seals against return flow therethrough, non-return valve 12 may be omitted. It is however preferred that a non-positive displacement air moving means be used so that it will continue to rotate during opening of assembly 13 when non-return valve 12 is closed. It will be appreciated from the foregoing that the levels of the biases on the mask outlet valve and on the diaphragm, or other pressure sensing means controlling valve 18, in relation to operation of the pump are critical to the effective and economic operation of the breathing apparatus. So far as the exhale valve is concerned, the differential pressure at which it opens may be in the range of differential pressures normally used for CABA or less, for example of the order of the ranges normally used for PAPR. The differential pressure at which the valve member 18 will open is however smaller than that normal for CABAs. Depending on the differential pressure at which the exhale valve will open in relation to operation of the pump, the exhale valve may under normal conditions of operation remain permanently open or may open and close with the breathing cycle of the wearer. If, under normal conditions of operation, the exhale valve remains permanently open, as the pressure maintained within the face mask drops towards the preset minimum, for whatever cause, the exhale valve will begin to close during inhalation.

An additional advantage of the above described apparatus is that it innately provides the wearer with an audible signal indicating that he is either overexerting himself or that the filter is becoming blocked or the battery is running down. Specifically, when the valve memer 18 opens, there is an audible hiss generated by the inlet of compressed air through the valve. If it is simply that the wearer's breathing rate is abnormally high, when he reduces his breathing rate the hiss will cease, the hiss in any event being intermittent. If it is a matter that the filter is becoming blocked or the battery is running down, the intermittent hiss will continue and indeed the period of the hiss will increase, and the wearer will know that, while he has a reserve period, which is determined by the capacity of the compressed air cylinder he is carrying, he must finish off his job or leave it in a safe condition and then leave the contaminated atmosphere. As an additional safeguard in the latter event, the cylinder regulator 34 may be fitted with a whistle warning device of conventional type which is arranged to sound when approximately 80% of the cylinder capacity has been used up.

It would appear from breathing machine tests that the performance of the above described apparatus is superior to either a positive pressure PAPR or a positive pressure CABA acting alone, and it is now thought that this may be due to the reduction in inertia effects of the assembly 13 due to its reduced use because the main volume of air supplied to the apparatus is supplied by the pump and filter means.

The face mask used in the above described embodiments is a conventional face mask comprising an outer mask covering the entire face of the wearer and an inner mask covering the nose and mouth of the wearer. The face mask is provided with an inlet opening in the outer mask opening into the space between the masks, and an outlet provided with the exhale valve communicating with the space within the inner mask, communication between the spaces between and within the masks being provided by openings in the inner mask provided with non-return valves. The apparatus described above may also be used with other conventional full or partial masks which cover at least the nose and mouth of the wearer and are provided with inlet and outlet means. For example, masks are known which are provided with two inlet openings. In use of such a mask with the above described apparatus, the outlet of the assembly 13 is connected to one inlet and the outlet of the pump, or one end of the flexible hose (where provided) connected thereto: is connected to the other inlet via a non-return valve (if required) which may be provided in the mask inlet or in the pump outlet. Use of the connector assembly 21 would thereby be avoided. Such an arrangement is shown in Figures 8 and 9 in which reference numerals used above are used for like parts. In this embodiment, the two mask inlets are identified by numerals 2a and 2b. Each inlet is provided with a non-return valve which correspond to valves 12 and 17 respectively. As shown in Figures 8 and 9, the pump unit and the filter unit are mounted directly on the face mask. In a modification, the pump unit may be connected to the inlet 2a by a flexible hose, as described above in relation to Figures 6 and 7.

It will be appreciated that the filter unit or units through which the ambient air is drawn by the pump in the above described embodiments may be designed to remove contaminants in the form of particulate materials and/or gases or vapours.

## Claims

1. Breathing apparatus comprising a face mask (1) for covering the nose and mouth of the wearer and having inlet means (2) and outlet means (3) for gas, non-return outlet valve means (4) being adapted for maintaining a positive differential pressure within said face mask, pump and filter means (6, 9) having an outlet (11) connected to the face mask inlet means for supplying filtered ambient air to said face mask, controllable valve means (13) having an inlet (14) for connection to a supply of pressurised breathable gas, and an outlet (16) connected to said face mask inlet means (2), and pressure sensitive control means (19, 20) for controlling said controllable valve means and adapted to cause opening of said controllable valve means (13) in the event that the pressure in said face mask falls below a preset minimum relative to ambient pressure, such that under normal operating conditions said controllable valve means (13) remains closed, filtered ambient air being supplied to said face mask by said pump and filter means.

2. Apparatus as claimed in claim 1, wherein said control means (19, 20) are adapted to cause closing of said controllable valve means (13) when the pressure within said face mask rises above a level above said preset minimum level.

3. Apparatus as claimed in either claim 1 or claim 2, wherein said pressure sensitive control means (19, 20) includes a diaphragm (19) arranged so that one face is subject to ambient pressure and the other face is subject to the pressure in the outlet of said controllable valve means.

4. Apparatus as claimed in any one of the preceding claims, wherein said controllable valve means (13) comprises a valve member (18) which is movable between open and closed positions and means are provided for causing movement of said valve member depending on the condition of said pressure sensitive control means (19, 20).

5. Apparatus as claimed in any one of the preceding claims, wherein said pump and filter means comprises air moving means (6) mounted in a pump housing (30) providing an inlet (7) and said outlet (11), a battery operated motor (29) connected for driving said air moving means (6) which is also mounted within said pump housing (30) and filter means (9) provided for filtering air entering said inlet of said pump housing.

6. Apparatus as claimed in claim 5, wherein said filter means comprises filter material in a filter housing having an inlet (10) and an outlet (8) connected to said pump housing inlet (7), said filter housing inlet (10) being open to the atmosphere.

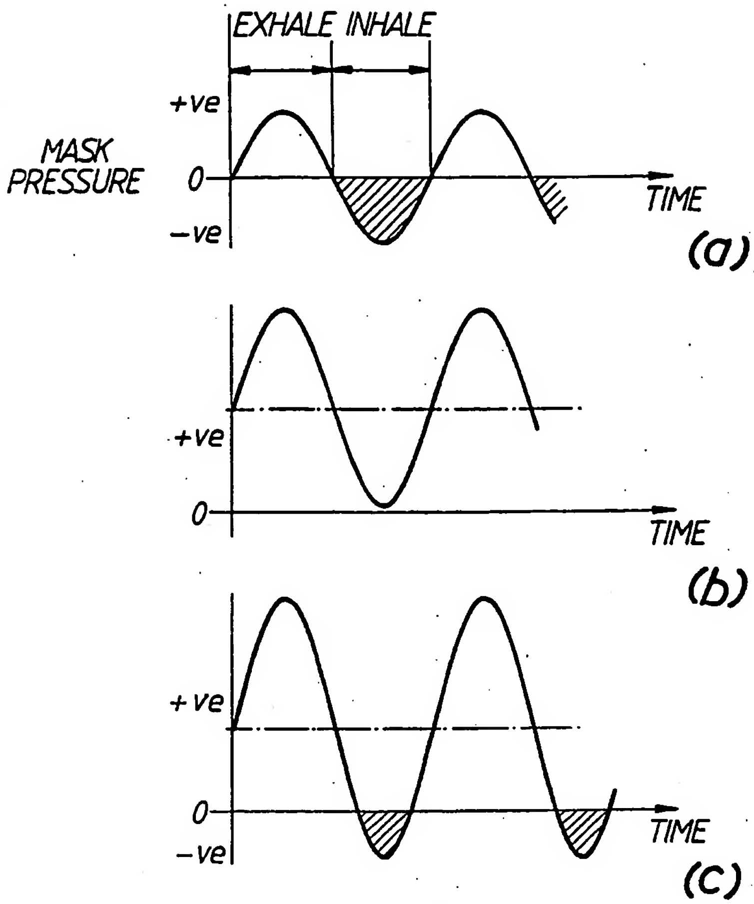
7. Apparatus as claimed in either claim 5 or claim 6, wherein said gas moving means comprises a fan (6) and non-return valve means (12) are provided in the path of flow of air from said pump (6) to said face mask for preventing reverse flow of breathable gas through said pump when said controllable valve (13) is open.

8. Apparatus as claimed in any one of the preceding claims, wherein said face mask inlet means (2) comprises a single inlet opening to which both the outlet (16) of said controllable valve means (13) and the outlet (11) of said pump and filter means (6, 9) are connected by connect ing means (21).

9. Apparatus as claimed in claim 8, wherein said means (21) connecting said outlet of said pump and filter means (6, 9) and said outlet of said controllable valve means (13) to said face mask inlet means (2) comprises a generally T-shaped connector having an upright and a cross-bar open at their ends, the open end (22) of the upright being connected to said face mask inlet (2) and the open ends (24, 25) of the cross bar being connected to the outlets of said controllable valve means (13) and of said pump and filter means respectively (6, 9).

10. Apparatus as claimed in claim 9, wherein non-return valves (12, 17) are mounted in said connector adjacent the open ends (24, 25) of said cross bar for preventing reverse flow of gas therethrough.

11. Apparatus as claimed in any one of the preceding claims, wherein said face mask inlet means (2) comprises two inlet openings (29, 26), said outlet of said pump and filter means (6, 9) being connected to one said inlet opening (29) and said outlet of said controllable valve means (13) being connected to said other inlet opening (26).


EXHALE INHALE
MASK PRESSURE
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TIME
(c)

FIG.1.

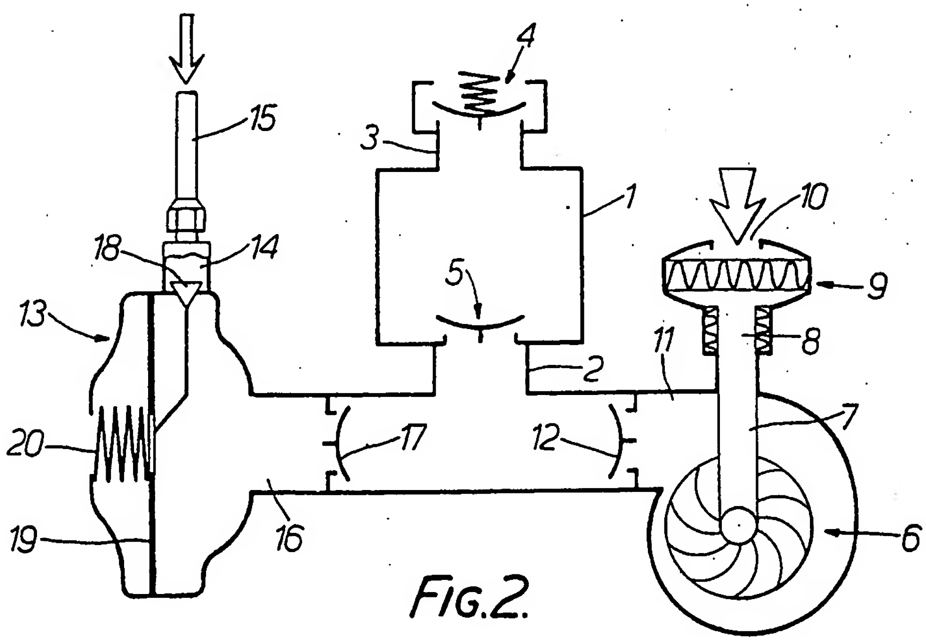
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FIG.2.

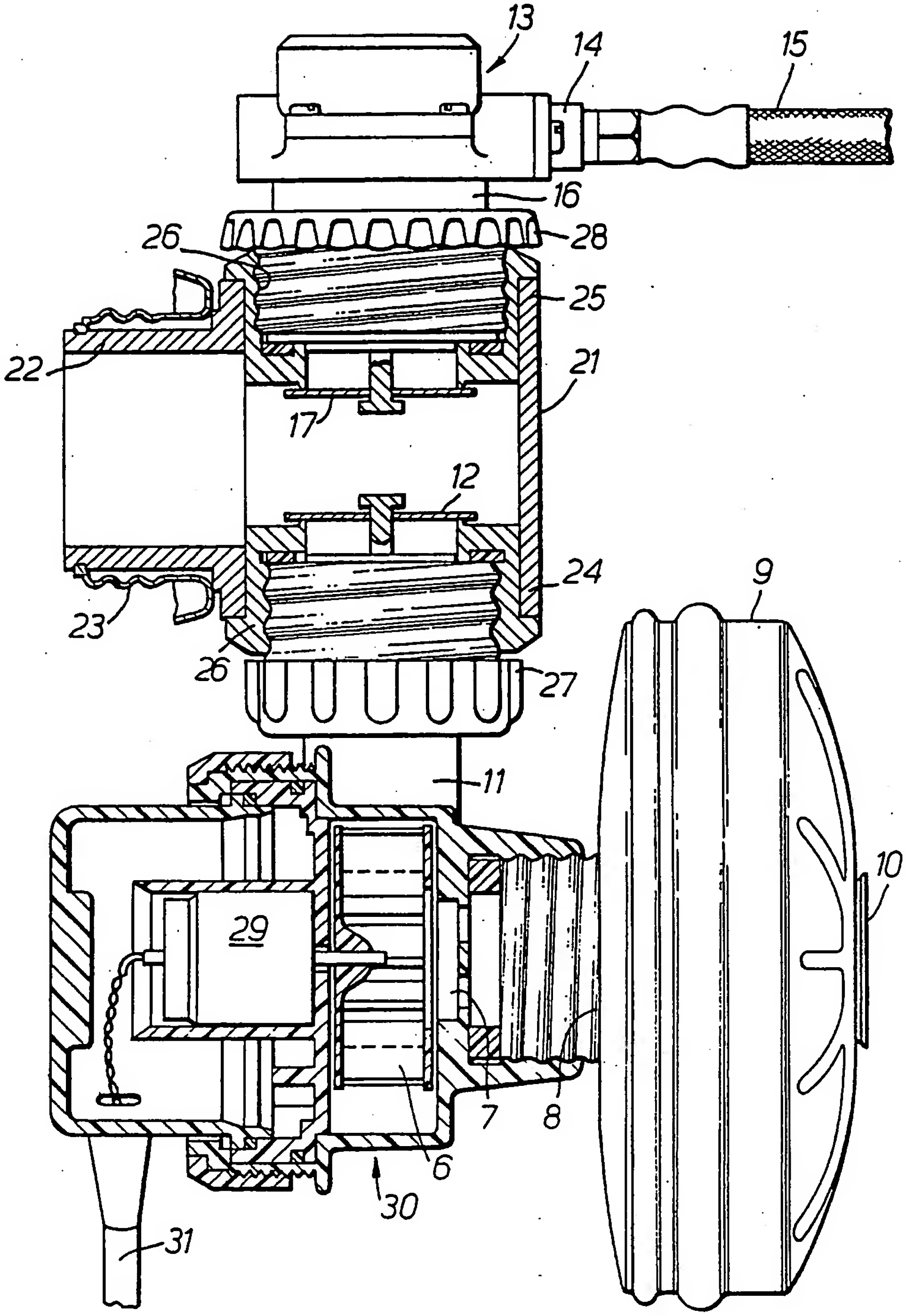


FIG.3.

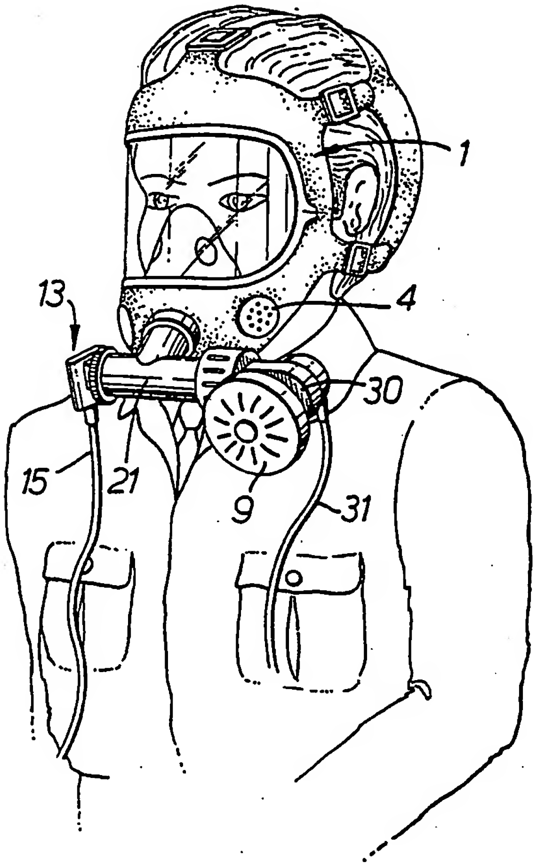


FIG.4.

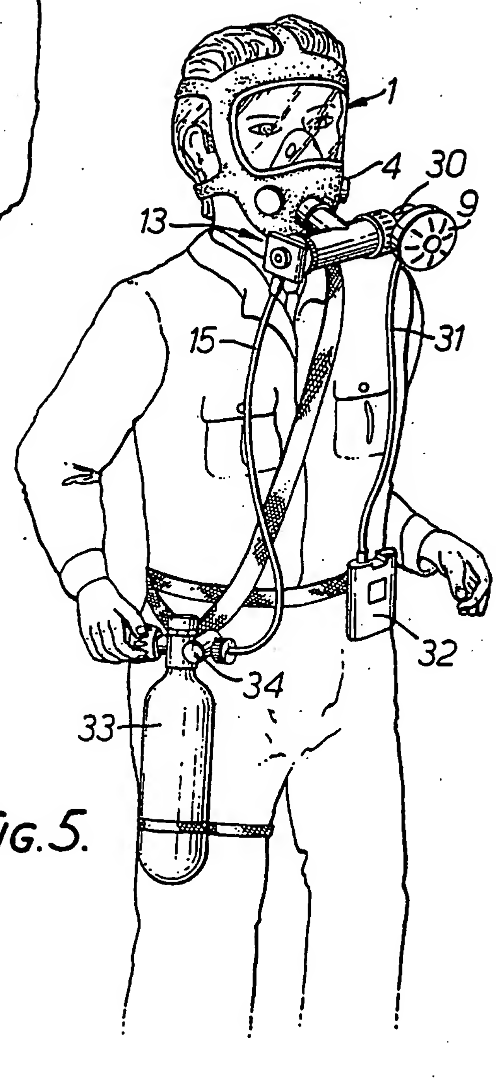


FIG.5.

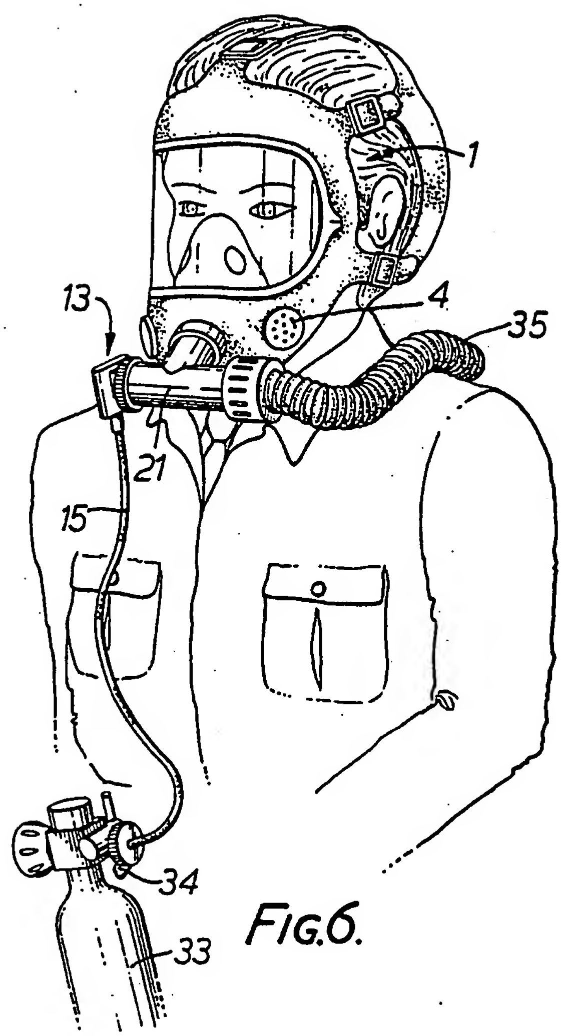


FIG.6.

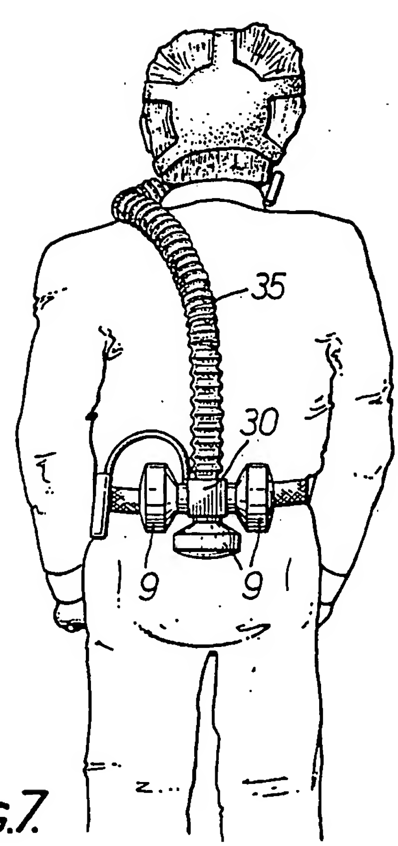


FIG.7.

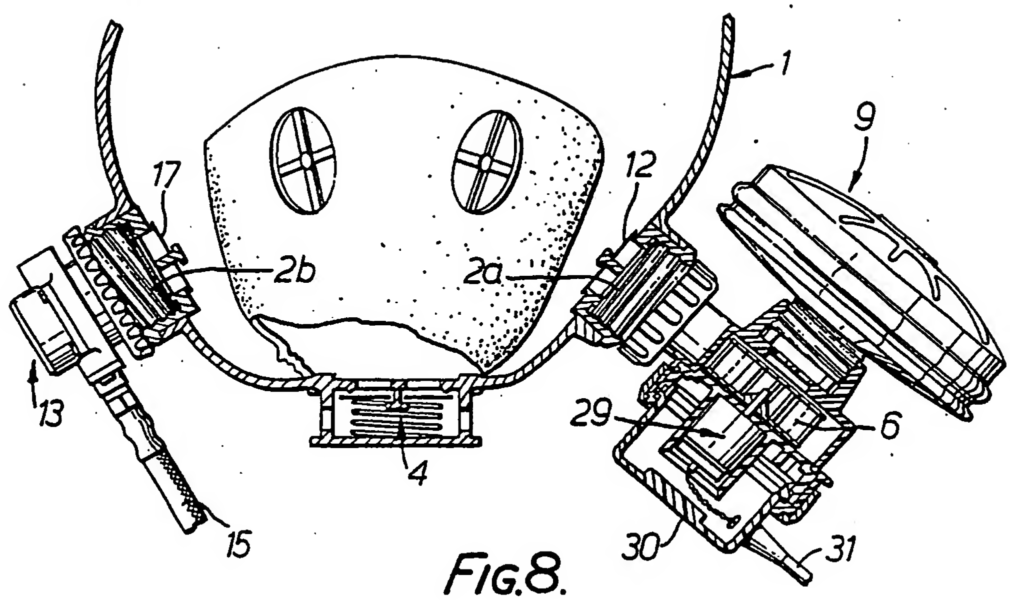


FIG.8.

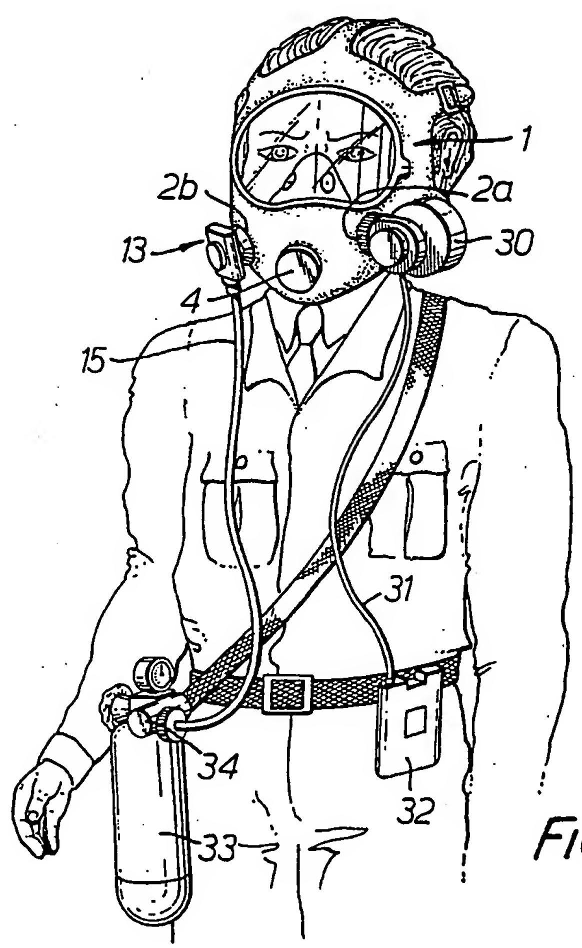


FIG.9.